



CARB Off-Road Mobile Source Technology Workshop
February 2-3, 2000 El Monte, California



Emissions Technologies for Off-Highway Compression Ignition Engines.

Peter Church

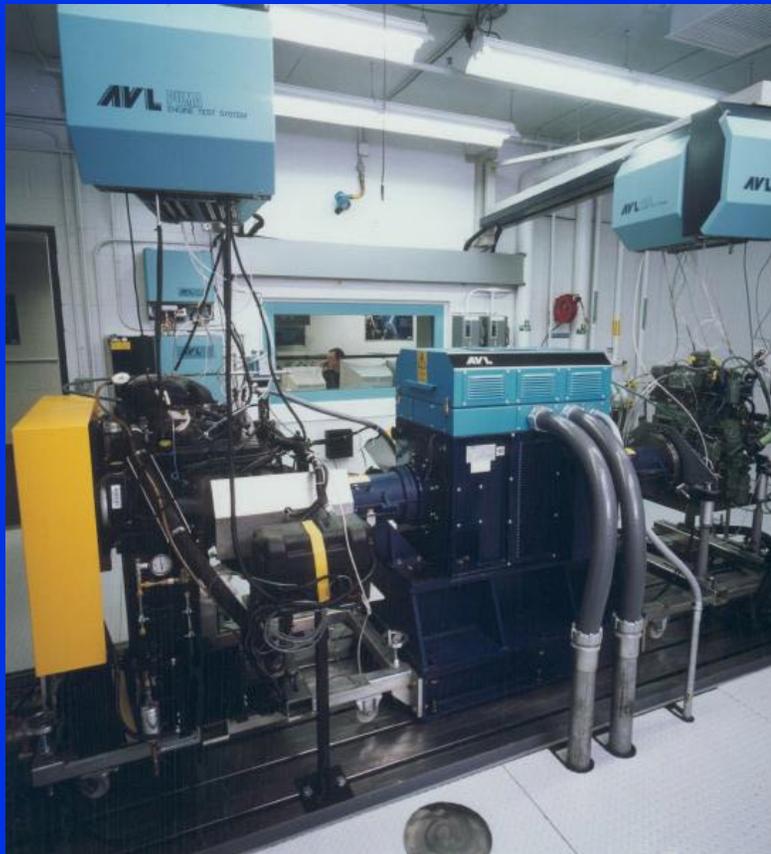
February 3, 2000

AVL Powertrain Engineering



Who is AVL ?

AVL



Largest Independent Powertrain Consulting Company

2400 employees worldwide

Privately owned

Total revenues more than \$300m

Based in Graz, Austria

US facility in Plymouth, MI

Business areas:

- > Development of powertrain systems**

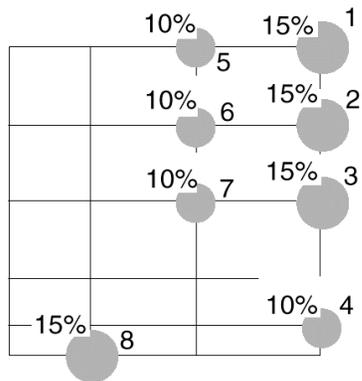
- > Instrumentation and test systems**



US EPA Non-Road Diesel Emission Limits 75 - 450 kw



C1
"Off-Road Vehicles,
Diesel Powered
Off Road Industrial
Equipment"



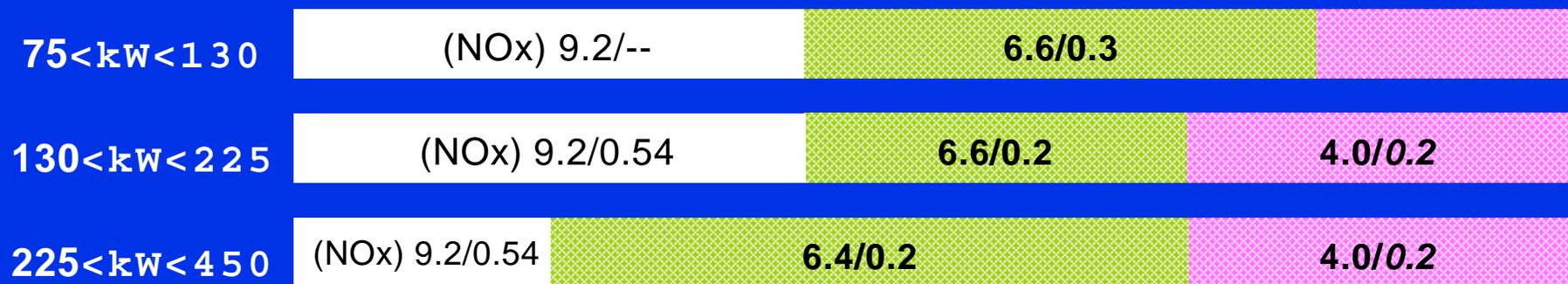
Test cycle and particulate limit to be reviewed by the EPA in 2001

NMHC+NO_x /PM
ISO 8178 C1 Test Cycle
[g/kW.h]

Tier 1

Tier 2

Tier 3





AVL considers the following technologies to be feasible options for Tier 3 non-road emissions control:

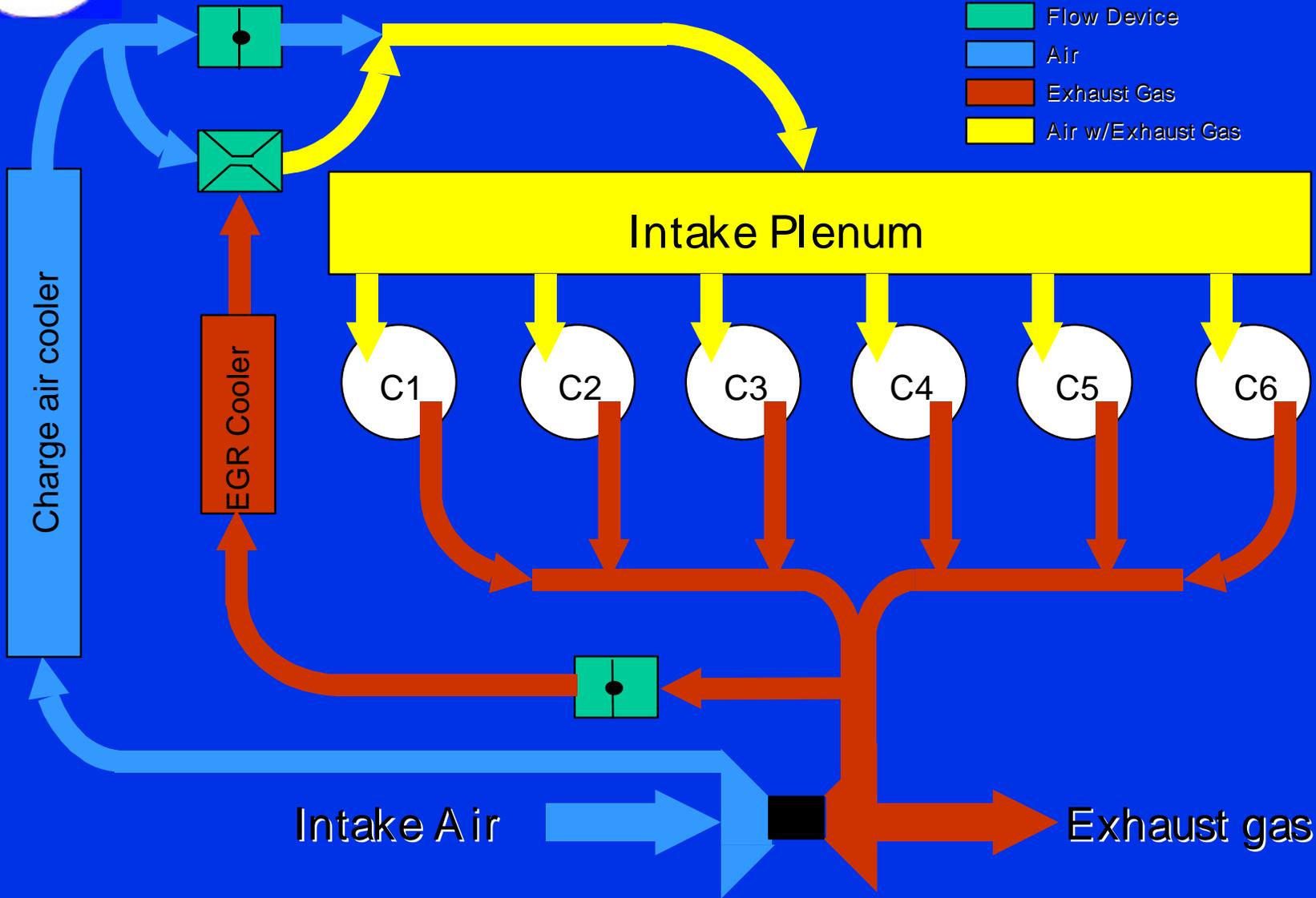
- Cooled Exhaust Gas Recirculation
- Advanced fuel system technology
- Improved diesel fuel
- Exhaust aftertreatment



COOLED EGR - BYPASS FLOW VENTURI CONCEPT



- Flow Device
- Air
- Exhaust Gas
- Air w/Exhaust Gas



Intake Air

Exhaust gas



Bypass Flow Venturi Concept:

Characteristics:

- **Venturi used to aid flow of exhaust gas to the intake manifold**
- **EGR rates of 6-8% at intermediate speed**
- **Moderate EGR rates at rated speed**
- **Moderate to high heat rejection rate**

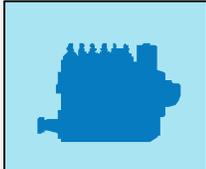
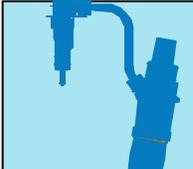
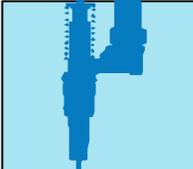
Applications:

- **Applications requiring good fuel economy**
- **Engines with little or no injection rate control or aftertreatment**



ADVANCED FUEL SYSTEMS - CAM DRIVEN TYPES



	Pump-Line-Nozzle Injection Systems			Unit Injector Systems
	Sleeve Timing In-Line Inj. Pump	High Pressure Rotary Pump	Unit Pump PLD-System	
				
Applicable Engine Class	medium-heavy duty	light-medium duty	light-heavy duty	light-heavy duty
Current Maximum Injection Pressure (bar)	1450	1400	1800	2200
Potential Maximum Injection Pressure (bar)	1600	1500	2200	2500
Natural Pressure Characteristic				
Injection Rate Shaping	Mech.: TSI, RSN Pre Inj. Helix (Pilot) Electron.: -	TSI, RSN	TSI, RSN Pilot	TSI, SID, RSN Pilot
Development and Application Activity	medium	high	high	medium (EU) high (USA)

 = Reference Injection Rate from In-Line Pump

6/033

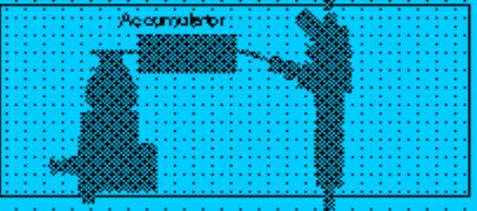
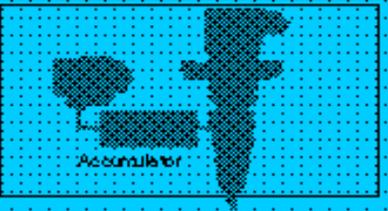
Unit pump and Unit injector systems are the preferred cam driven types:

- Higher maximum injection pressure and favorable pressure characteristics
- Capable of pilot injection and “boot” injection



ADVANCED FUEL SYSTEMS - COMMON RAIL TYPES



High Pressure Common Rail Systems		Intensifier Systems	
			
Applicable Engine Class	light - heavy duty	Applicable Engine Class	light - heavy duty
Current Maximum Injection Pressure (bar)	1400	Current Maximum Injection Pressure (bar)	1500
Potential Maximum Injection Pressure (bar)	1800	Potential Maximum Injection Pressure (bar)	1800
Natural Pressure Characteristic		Natural Pressure Characteristic	
Injection Rate Shaping	Mechanical: - Electronic: Pilot	Injection Rate Shaping	Mechanical: PRIME Electronic: -
Development and Application Activity	high	Development and Application Activity	medium

 = Reference Injection Rate from In-Line Pump

Both systems will have similar capabilities:

- Hydraulic intensifier system may prove advantageous if hydraulic power from the pump can be used with other vehicle systems. New digital valve types can provide pilot injection.
- High pressure common rail system could share high volume with passenger car types, reducing cost



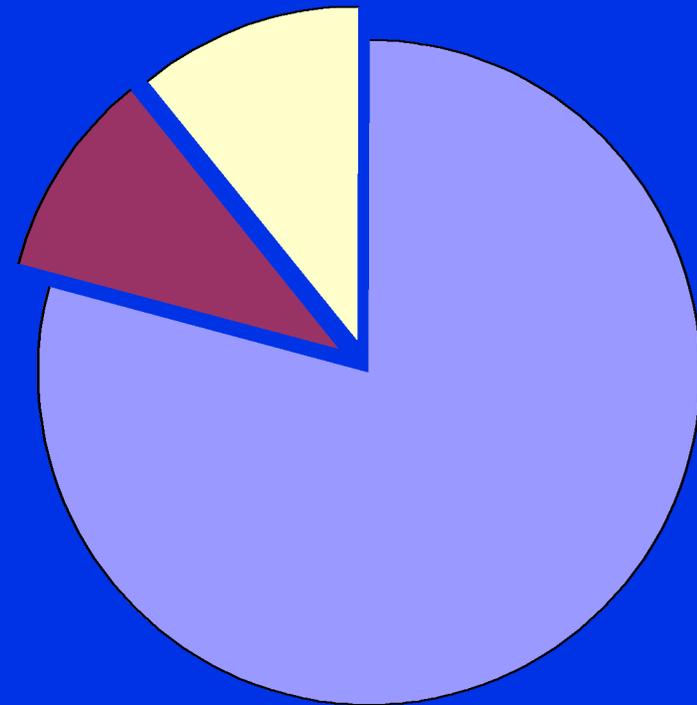
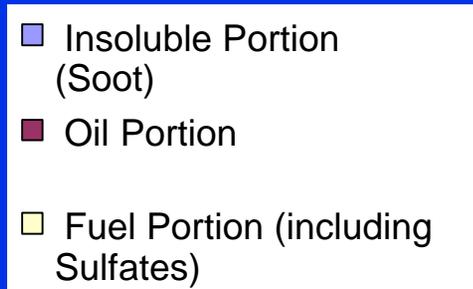
Electronic control provides many advantages at Tier 3 emissions levels:

- **Reduced soot in oil for engines**
- **Improved cold starting**
- **Rating flexibility**
- **Reduced combustion noise**



Particulate reduction:

- **Reduced sulfur content provides a direct reduction in particulates due to reduced sulfates in the particulate matter**





For off-highway diesel engines, fuel sulfur level will be critical if aftertreatment is employed:

Particulate reduction:

- CRT (Continuously regenerating trap) - Requires fuel Sulfur levels below 50 ppm**
- Oxidation catalyst - Requires fuel Sulfur levels below 500 ppm**

NOx Reduction:

- De-NOx catalysts using diesel fuel post-injection require fuel Sulfur levels below 10 ppm**



- **SCR (Selective Catalytic Reduction) - Requires a separate onboard supply of reducing agent.**
- **OBD is required to indicate lack of additive and to control trap loading.**
- **Low Sulfur fuel is not required with SCR**



Durability connects emissions reductions that are possible to emissions reductions that are practical. The main durability issues for Tier 3 are:

- EGR control component durability**
- Turbocharger durability**
- Soot loading in the lube oil**
- Aftertreatment device durability**